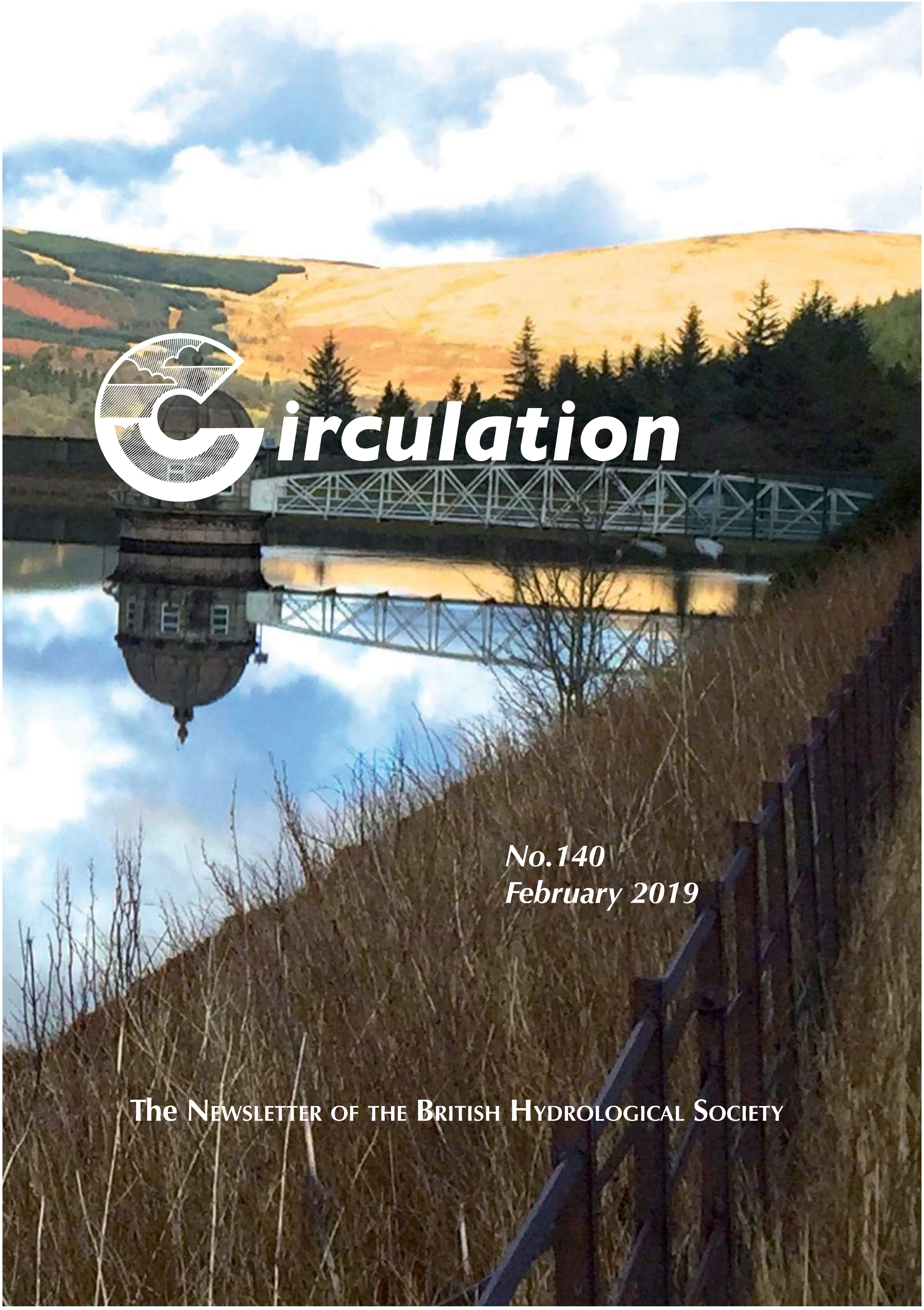

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Contents

Copy deadline for Circulation No. 141 24th April 2019

Final Call!

15 February

is the deadline for Applications for BHS grants for EGU, Vienna, April 2019. Please get your forms in to the Treasurer in time.
Full details of conditions and how to make a submission are given on the website under 'Conference Grants'

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President's Piece

Those of you who were at the Symposium in September will no doubt recall the informative and challenging keynote presentation by Keith Beven, FRS. One of the benefits of Keith's election to the Royal Society is that it gives him a platform for promoting hydrology, and an element of support for doing so. One of the things he is doing is to set up a group to discuss research priorities for hydrological science, something that I wholeheartedly support on behalf of BHS.

It is gratifying that the request for expressions of interest in joining this group drew a wide response, though it is of course a pity that Keith has had to disappoint a substantial number of those who applied. If you were one of those I hope you will find other ways to contribute your thoughts, perhaps through a BHS meeting, or an article for *Circulation*. And of course we look forward to dissemination of the work of the research group in due course.

In the last few months we have seen important developments in surely the most important issue of our time (yes, even more important than Brexit …). Whilst the long-awaited publication of UKCP18 may not directly impact on some of the research topics that Keith's group will be discussing, it will influence a great deal of what many of us do in the coming years. One of the gratifying features of UKCP18 is the access to the datasets, something that has not always been straightforward in the UK, at least for those of us not working in academia. I'm pleased that access to data has improved in other areas too – top marks to the person in SEPA who recently supplied me with data that went up to literally just a few hours prior to his email reaching me. More of that from all organisations, please!

Whilst it is always important to look forward, it is instructive also to look back, and one of the pleasures of my last 3 months was to represent BHS at the Thanksgiving Service to celebrate the National Year of Engineering, also marking the 200th anniversary of the ICE. As the President of ICE remarked afterwards, if a few years ago someone had said that Westminster Abbey would be packed with 2000 people from a wide range of backgrounds to celebrate engineering he would have thought it was a wind-up.

Now I know that many of you are not Engineers (at least with a capital E), but most of what we all do is in the end based on the desire to engineer a better future, and it was very good to look both back and forward at this event. In relation to the future, the diversity of the speakers in the Abbey was commendable. Which brings me to BHS where the committee has discussed the (at times) limited visible diversity in some of our activities. We are conscious of the need for, and benefits of, greater diversity in our meetings, and I encourage all of you to get involved in whatever way you can.

Finally, I was delighted to write to Terry Marsh to inform him of the committee's decision to elect him as an Honorary Member of BHS. Terry's contribution to British hydrology is covered elsewhere in this issue.

Peter Ede
President

Adjustment of QMED in ungauged catchments using two donor sites

Thomas Rodding Kjeldsen

This note proposes an analytical method for adjusting a purely catchment-descriptor based estimate of QMED with AMAX data from two nearby donor sites. The method is based on the QMED catchment descriptor equation published as part of the improved FEH statistical method (Environment Agency, 2008) and is an extension of the procedure for using one donor site from the same publication. The first section gives a summary of the method, the second section provides an example of how to use the method, and finally details of the theoretical derivation are provided for anyone interested. I presented a general framework for using multiple donors in Kjeldsen et al. (2014) and have adapted it here for the case of two donors.

Data transfer from two donor sites – a summary

According to the improved FEH statistical method (Environment Agency, 2008), estimating QMED based on catchment descriptors is based on the following equation:

$$QMED = 8.3062 AREA^{0.8510} 0.1536^{\frac{1000}{SAAR}} FARL^{3.4451} 0.0460^{BFIHOST^2} \quad (1)$$

When adjusting the catchment-descriptors-only estimate of QMED at the subject site using two donors, Kjeldsen et al. (2014) suggested the following equation could be used

$$QMED_{s,adj} = QMED_{cd,s}\left(\frac{QMED_{1,obs}}{QMED_{1,cd}}\right)^{\omega_1}\left(\frac{QMED_{2,obs}}{QMED_{2,cd}}\right)^{\omega_2} \quad (2)$$

where subscripts s, 1 and 2 refer to the subject site and donor sites 1 and 2, respectively, and ω_1 and ω_2 are weights that must be determined. The subscripts *obs*, *cd* and *adj* refer to estimates of QMED obtained using: observed AMAX data, catchment descriptors only, Eq.(1), and, finally, the donor adjusted estimate. The method differs from the method proposed for multiple donor adjustment in FEH Volume 3, page 18 which gives no specific guidance on how to specify the weights when using more than one donor. Here the strategy pursued is that the most desirable estimate has the lowest possible uncertainty, which result in the following expressions of the weights ω_1 and ω_2 from Eq. (2):

$$\omega_1 = \frac{\rho_{s1} - \rho_{12}\rho_{s2}}{1-\rho_{12}^2}$$

$$\omega_2 = \frac{\rho_{s2} - \rho_{12}\rho_{s1}}{1-\rho_{12}^2} \quad (3)$$

where ρ_{ij} is a function of the Euclidian distance, d_{ij}, between centroids of catchment i and j, as measured in kilometres and given as

$$\rho_{ij} = 0.4598exp(-0.020d_{ij}) + (1 - 0.4598)exp(-0.4785d_{ij}) \qquad (4)$$

When used for donor adjustment in Eq.(2) the weights in Eq.(3) give the value of $QMED_{s,adj}$ associated with the lowest possible level of uncertainty. Here, as in Kjeldsen (2015), the uncertainty of QMED is measured using the factorial standard error (*fse*) which for$QMED_{s,adj}$ in Eq.(2) is given as:

$$fse = exp\left(s\sqrt{1 - \rho_{s1}^2 - \rho_{s2}^2 + 2\rho_{s1}\rho_{s2}\rho_{12}}\right) \qquad (5)$$

where *s* is the standard error of the model error variance for the QMED equation in Eq. (1) and given by Kjeldsen & Jones (2009) as *s*=0.1286. The 95% confidence interval for $QMED_{s,adj}$ can then be calculated as:

[$QMED_{s,adj}$/fse^2 ; $QMED_{s,adj}$ ×fse^2].

In the following sections a small example of application is presented, building on some previously published results published by Kjeldsen (2015). This is followed by a theoretical derivation of the weights in Eq.(3).

Example of QMED adjustment using two donors

The example here follows the example used in Kjeldsen, 2015) who considered different strategies for using local AMAX data to improve estimates of QMED in ungauged catchments. This paper considered estimates of QMED for the catchment draining to gauging station 56013 using one donor site (Donor site 1); the nearby 56003. A second gauging station with a long records of high quality flood data, a hydrologically similar catchment and within a 50 km geographical proximity is 54025 River Dulas at Rhos-y-pentref (Donor site 2), where 39 AMAX data are available for the period 1970--2008. A summary of the catchment descriptors for the subject site and each of the donor sites is shown in Table 1, while Table 2 shows the geometric distance between the catchment centroids (i.e. the values of d_{ij} for use in evaluation of Eq.(4)).

Table 1: Catchment descriptors for the subject site and each of the two donor sites

Catchment descriptors	*Subject site 56013*	*Donor site 1 56003*	*Donor site 2 54025*
East (centroid) [m]	297 622	302454	296 856
North (centroid) [m]	238 444	237 136	278 995
Area [km^2]	63.27	62.50	53.17
SAAR [mm]	1299	1171	1268
FARL [-]	1.000	0.999	1.000
BFIHOST [-]	0.494	0.528	0.439
$QMED_{obs}$ [m^3/s]	36.6	23.5	23.2
$QMED_{cd}$ [m^3/s]	31.6	23.9	30.8

Table 2: Distance between catchment centroids (km)

	Subject site	*Donor site 1*	*Donor site 2*
Subject site	-	5.0	40.6
Donor site 1	-		42.2
Donor site 2			-

Table 3: Correlation function, Eq. (4)

	Subject site	*Donor site 1*	*Donor site 2*
Subject site	-	0.47	0.20
Donor site 1		-	0.20
Donor site 2			-

The first step involves calculation of the correlation function ρ_{ij} in Eq.(4) using the distances in Table 2 and reported in Table 3. Next, the two weights ω_1 and ω_2 are calculated using the expression in Eq.(3) combined with the correlations in Table 3.

$$\omega_1 = \frac{0.47-0.20\times0.20}{1-0.20^2} = 0.45$$

$$\omega_2 = \frac{0.20-0.20\times0.47}{1-0.20^2} = 0.12$$

Finally, the adjusted estimate of QMED is obtained using Eq.(2), i.e.

$$QMED_{s,adj} = 31.6\left(\frac{23.5}{23.9}\right)^{0.45}\left(\frac{23.2}{30.8}\right)^{0.12} = 30.3\ m^3/s$$

Note that at both donor site 1 and 2 the estimates of QMED obtained from catchment descriptors only are smaller than the medians of the observed AMAX data. Also, there is no requirement for the two weights to sum to one. For example, if both donor sites are located very far away from the subject site, then the adjusted QMED simply convert towards the catchment-descriptor only estimate.

The associated factorial standard error of the adjusted QMED is calculated using Eq.(5) as

$$fse = exp\left(0.1286\sqrt{1-0.47^2-0.20^2+2\times0.47\times0.20\times0.20}\right) = 1.32$$

Table 4 shows a comparison between the results obtained here using two donors and selected results from Kjeldsen (2015) based on the catchment-descriptors only QMED model (Eq. 1) and the use data transfer from only donor site 1.

Table 4: *Estimates of QMED and fse for the subject site using selected methods*

Method	QMED [m^3/s]	fse
Gauged (*n*=36)	36.6	1.08
Regression only	31.6	1.43
Regression + 1 donor	31.3	1.37
Regression + 2 donors	30.3	1.32

As can be seen in Table 4, there is only a minor change to the numerical value of the QMED value itself, but the fse has been reduced from 1.37 when using a single donor to 1.32 when including a second donor site into the analysis. Note also that at both donor sites, QMED from the catchment descriptor equation was smaller than QMED obtained from AMAX data, which reduces the adjusted QMED estimate.

Theoretical derivation of optimal weights

The derivations in this section follow the methodology developed by Kjeldsen and Jones (2007) for a single donor and later extended by Kjeldsen et al. (2014) to consider multiple donors. While it is possible to derive analytical expressions for weights when using more than two donors, these expressions quickly become very cumbersome and relatively little is gained in terms of precision. In an attempt to make the derivations clearer, the natural logarithm of QMED is denoted y and the following notation introduced for different log-transformed estimates of QMED:

- y: estimate obtained using observed AMAX data
- $\hat{y}$: estimate obtained using catchment descriptors (only)
- $\tilde{y}$: estimate obtained through donor adjustment

The associated subscripts are defined as:

- s: subject site
- 1: donor site number 1
- 2: donor site number 2

Starting from Equation (5) in the paper by Kjeldsen et al. (2014), for p = 2 donor sites the adjusted estimate of log-transformed QMED is

$$\tilde{y}_s = \hat{y}_s + \omega_1(y_1 - \hat{y}_1) + \omega_2(y_2 - \hat{y}_2) \tag{6}$$

This is equivalent to taking the natural logarithm of Eq. (2) in this note and adopting the notation above. Ignoring the sampling variance of the at-site estimators (error arising from estimating QMED using a finite number of AMAX events) as this is much smaller than the regression errors, the variance of the differences in the parenthesis can be considered just based on regression errors. All three terms on the right-hand side of Eq. (6) therefore have the same variance, and the total variance of the adjusted log-transformed QMED estimate $V\{\tilde{y}_s\}$ can be approximated as:

$$V\{\tilde{y}_s\} \approx \sigma_\eta^2 + \omega_1^2\sigma_\eta^2 + \omega_2^2\sigma_\eta^2 - 2\omega_1 cov\{\hat{y}_s, \hat{y}_1\} - \\ 2\omega_1 cov\{\hat{y}_s, \hat{y}_1\} - 2\omega_2 cov\{\hat{y}_s, \hat{y}_2\} + 2\omega_2\omega_1 cov\{\hat{y}_1, \hat{y}_2\} \tag{7}$$

where σ_η^2 is the variance of the regression model errors given by Kjeldsen & Jones (2009) as σ_η^2=0.1286^2 and is constant for all catchments. Again ignoring the effect of sampling noise, the covariance between two estimates of catchment-descriptor estimates $\hat{y}$ at two different sites is given as

$$cov\{\hat{y}_i, \hat{y}_j\} = \sigma_\eta^2\rho_{ij} \tag{8}$$

where the correlation between the model errors at the two sites is given by Kjeldsen & Jones (2009) as per Eq. (4) in this note, and based on the distance between catchment centroids.

The optimal set of weights is determined here as the values that minimises the variance of the adjusted log-transformed QMED (Eq, 7 above), i.e.

$$\frac{\partial V\{\tilde{y}_s\}}{\partial \omega_1} = (2\omega_1 - 2\rho_{s1} + 2\omega_2\rho_{12})\sigma_\eta^2 = 0$$

$$\frac{\partial V\{\tilde{y}_s\}}{\partial \omega_2} = (2\omega_2 - 2\rho_{s2} + 2\omega_1\rho_{12})\sigma_\eta^2 = 0 \qquad (9)$$

Solving this set of equations for ω_1 and ω_2 gives the equations

$$\omega_1 = \frac{\rho_{s1} - \rho_{12}\rho_{s2}}{1-\rho_{12}^2} \qquad (10)$$

$$\omega_2 = \frac{\rho_{s2} - \rho_{12}\rho_{s1}}{1-\rho_{12}^2}$$

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